Microwave Surface Resistivity of Several Materials at Ambient Temperature

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Microwave surface resistivity of a number of metal and other sample materials was measured at X-band, approximately 8400 MHz. The method of measurement uses a TE_{011} mode circular waveguide cavity resonator wherein the sample is used as one end of the cavity. This method has been used previously in JPL work with good results. Microwave reflection loss and noise arising from the dissipative loss are given, for materials having negligible transmission leakage.

I. Introduction

Previous work at JPL derived the properties of the TE_{011} resonator and demonstrated valid experimental results on a few materials (Ref. 1). Later work concentrated on an evaluation of various flame-spray metallized fiberglass-epoxy materials, accomplished with assistance from the Harris Corporation, Melbourne, Florida (Ref. 2). Later, Ford Aerospace, Palo Alto, California, under a work order issued by the Ground Antennas and Facilities Engineering Section, concentrated on understanding the dual carrier intermodulation generation characteristics of a different set of flame-spray samples. No serious attempt to obtain precise knowledge of the reflection loss of those samples was made at that time. More recently, in connection with the JPL 70-m Antenna Rehabilitation and Upgrade Project (Ref. 3), several questions arose with respect to resistivity and surface finish of candidate materials for a proposed cast aluminum subreflector. This reporting covers (1) several control samples, (2) a collection of commonly available metals, (3) candidate 70-m subreflector materials, (4) a repeat of some of the earlier Harris Corporation samples which have been retained at JPL, and (5) a repeat of some of the earlier Ford Aerospace samples which have been retained at JPL. This reporting therefore represents an assemblage of new work and repeats of portions of older work. Some of the older flame-spray samples are approximately 36 months old.

II. Experimental Setup

The experimental setup was essentially that shown in Ref. 2, with provision to switch the cavity in and out of the test channel, for rapid insertion loss measurement. Also, to speed the measurement of the large number of samples, the signal generator was not synthesized for high-frequency stability; a frequency resolution of about 5 kHz was accepted. The estimated absolute accuracy of the results is about 15% on a high confidence basis; the observed repeatability and relative precision among various samples is about three times better than the absolute accuracy. We emphasize that this cavity method of resistivity measurement is capable of considerably better accuracy and precision if needed; the work reported herein had the goal of determining resistivity of a large collection of samples in short time rather than an accuracy/precision demonstration.

III. Results

Table 1 gives measured resistivity in ohms (per square) and derived reflection loss and associated noise for some 30 samples. It should be appreciated that any material having some transmission (leakage) component, such as a mesh or other perforated material, will be overestimated. That is, a leaky material will cause the cavity technique to assess the reduced cavity loaded quality factor (Q_L) as all due to surface resistivity whereas the truth is that an unknown portion of the assessment is due to resistivity and the balance due to leakage. Such materials are indicated in Table 1 as starred and footnoted. In Table 1 the control materials (Silver plate on brass, Copper sheet and OFHC Copper) were continually referred to during the course of the measurements. The aluminum series included two samples each of 70-m Project candidate machining techniques, having about 10 periods per lineal inch (25 mm) of 125, 250 and 500 microinch (0.003, 0.006, and 0.013 mm) RMS surface finishes. Such finishes arise from 3-axis milling machine treatment necessary for an asymmetric (not figure of revolution) shaped surface subreflector. It should be noted that the small scale surface finish (scale size <0.1 inch or 2.5 mm) of these materials is perhaps 32 microinch (8×10^{-4} mm), and as the measurements show, the resistivity appears consistent with this small scale size finish rather than the large scale size (~ 1 inch or 25 mm). The proposed casting alloy (Aluminum type 319-2F) appears suitable, although about 20% higher resistivity than Aluminum type 6061-T6.

Intentionally, we sought to demonstrate lossier materials such as stainless and mild steel as well as others. Some of the others were indeed very high resistance. In these cases the cavity resonant frequency was shifted considerably upwards (order of 100 MHz or 1.5%). Under these conditions, care must be exercised to remain with the intended TE_{011} mode.

Table 2 gives measured resistivity and derived reflection loss and associated noise for some 10 flame-sprayed samples. These samples include the lowest and highest expected resistivities from batches prepared by two different suppliers at two different times. The Harris Corporation (HARR) samples were prepared in 1981 (Ref. 2), and are all "as sprayed." The Ford Aerospace (FACC) samples were prepared in early 1984 and are similarly "as sprayed." The work accomplished earlier by Ford Aerospace included studies of buffed surfaces, in attempts to amalgamate individual flame-spray "beads" into a more continuous surface. Some indications were that buffing produced a lower intermodulation product generation. We did not test the buffed surfaces in the belief that any sizeable reflector could not be adequately quality controlled by such hand finishing. As can be seen in Table 2, flame-spray techniques are from two to four times higher resistivity than 6061 T6 Aluminum plate.

In DSN antenna service, with 400 KW CW X-band power incident upon a subreflector, the lowest resistivity material (Silver plate on brass) would dissipate about 100 watts. A good practical material (6061 T6 Aluminum) would dissipate about 160 watts. The best flame-spray (FACC 1/6) would dissipate about 300 watts while the highest resistivity sample (FACC 1/7) would dissipate 600 watts. The type 319-2F casting alloy will dissipate about 190 watts.

IV. Summary

A previously developed and demonstrated technique for microwave surface resistivity measurement was applied to some 40 samples in a less sophisticated test setup. The object of these measurements departed from previous work in that highest accuracy and resolution were not the purpose, although very excellent results were nevertheless obtained. It was determined that the candidate material and processing method for the DSN 70-m subreflector is entirely acceptable at X-band. However, some caution is suggested with regard to frequency scaling (e.g., to 32 GHz), particularly for the 500 microinch sample. One may note that the 10 periods per lineal inch characteristics of this material will represent fewer ridges and valleys per wavelength at 32 GHz, compared to 8.4 GHz. For purposes of the 70-m subreflector machining, we would prefer the finer finishes, with eventual 32 GHz application in mind. Several flame-sprayed samples show a variation of a factor of two in resistivity, from twice to four times that of a 6061 T6 type Aluminum.

References

1. Jet Propulsion Laboratory, 1972, *The Deep Space Network, Vol. 12*, JPL TR 32-1526, 59-67, Pasadena, Calif.

2. Thom, E. H., and T. Y. Otoshi, 1981, Surface resistivity measurements of candidate subreflector surfaces, *TDA Progress Report 42-65*, 142-150, Jet Propulsion Laboratory, Pasadena, Calif.

3. McClure, D. H., and F. D. McLaughlin, 64-meter to 70-meter antenna extension, *TDA Progress Report 42-79*, 160-164 Jet Propulsion Laboratory, Pasadena, Calif.

Table 1. Resistivity, reflection loss and noise at 8400 MHz for various materials

Material	R_s, ohms per square	Refl. loss, dB	Noise, K
Silver Plate on Brass	0.0239	0.0011	0.07
Silver Plate on Brass	0.0243		
Silver Plate on Brass	0.0244		
Copper Sheet	0.0240		
Copper Sheet	0.0252		
Copper (OFHC)	0.0267	0.0011	0.07
Alum. 6061T6, 125 m/inch	0.0360	0.0018	0.12
Alum. 6061T6, 125 m/inch	0.0400		
Alum. 6061T6, 250 m/inch	0.0378		
Alum. 6061T6, 250 m/inch	0.0385		
Alum. 6061T6, 500 m/inch	0.0375		
Alum. 6061T6, 500 m/inch	0.0382		
Alum. 6061T6, Plate	0.0368		
Alum. 5052, Plate	0.0407	0.0018	0.12
Alum. 2024, Plate	0.0446	0.002	0.14
Alum. 319-2F, Cast Alloy	0.0446		
Brass Plate	0.0481		
Galvanized Steel (Zinc)	0.0464	0.002	0.14
Perf. Alum. Plate (1/8" × 40%)	0.115[a]	0.005	0.36
Flame Spray (uncontrolled)	0.147	0.007	0.45
St. Steel 304	0.164	0.008	0.51
St. Steel 347	0.218	0.010	0.67
Titanium Plate	0.229	0.010	0.67
Mild Steel	0.332	0.015	1.03
St. Steel 321	0.347	0.016	1.07
St. Steel (unknown)	0.663	0.031	2.05
Rhomoglas on Balsa	3.49	0.164	11
Rhomoglas 1/2-3" fibres/2%/polyester	29.2[a]	1.2	80
40% Alum. flakes/EMI X540 polycarb.	31.0[a]	1.2	80
30% Carbon fibre DC-1006 polycarb.	50[a]	1.75	120

[a]Partially transmissive (leaky)

Table 2. Resistivity, reflection loss and noise at 8400 MHz for flame sprays

Material[a]	Rs, ohms per square	Refl. loss, dB	Noise, K
FACC 1/6 Pure Zinc	0.0712	0.0033	0.22
FACC 1/4 Pure Copper	0.0715	0.0033	0.22
FACC 1/5 Pure Silver	0.0779	0.0036	0.24
FACC 1/3 Pure Zinc-Tin	0.0909	0.0042	0.28
HARR 3 Std Al + Cu	0.0911	0.0042	0.28
HARR 2 Std Al + Cu	0.0936	0.0042	0.28
FACC 1/2 Pure Al	0.1356	0.0063	0.42
HARR 1 Std Al	0.1394	0.0063	0.42
HARR 2 Std Al	0.1413	0.0065	0.44
FACC 1/7 Std Al (10% impurity)	0.1490	0.0069	0.46

[a]FACC = Ford Aerospace. All using hi-temperature release agent.
HARR = Harris Inc.